Quick Facts about Alloy Steels

SIXTH EDITION

BETHLEHEM STEEL COMPANY
BETHLEHEM, PA.

Tapping a 50-ton tilting electric furnace.

SOME time ago we began publication of a series of advertisements dealing with basic facts about alloy steels. These advertisements, published in several leading industrial and technical magazines, evoked immediate response, and led to many requests for copies.

The information set forth in this series of advertisements is now presented in more convenient form in this booklet. Though much of the information is elementary, we believe it will be of interest to many in this field, including men of broad experience who may find it useful to review fundamentals from time to time.

Steel

For Strength
. . . Economy
. . . Versatility

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What Is an Alloy Steel?

Here is an easy definition to remember: An alloy steel is a grade of steel in which one or more alloying elements have been blended to give it special properties that cannot be obtained in carbon steel.

Or, here is the metallurgical definition: An alloy steel is one in which the maximum specified content of alloying elements exceeds one or more of the following limits —

Manganese, 1.65 pct; Silicon, 0.60 pct; Copper 0.60 pct

or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized commercial field of alloy steels: aluminum, boron, chromium up to 3.99 pct, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium, or any other element added to obtain a desired alloying effect.

As a rule, alloy steel is more difficult to make than carbon steel. There are more elements to be kept within specified ranges and, in general, the ranges of the alloying elements are comparatively narrow; hence the mathematical chances for producing off-heats are correspondingly increased. Moreover, most alloy steels require special reheating and cooling to prevent such imperfections as flaking and cracking.

Surface imperfections must be removed from the billets by scarfing, chipping, or grinding. More exacting methods of testing and inspection are necessary to insure uniformity.

WHERE DOES IT PAY TO USE ALLOY STEELS?

Generally speaking, it is advisable to use alloy steel when more strength, ductility, and toughness are required than can be obtained in carbon steel in the section under consideration. Alloy grades should also be used where specific properties such as corrosion-resistance, heat-resistance, and special low-temperature impact values are needed.

Effects of Elements

To simplify a rather complex subject, let's outline some of the individual effects of four leading alloying elements:

Nickel—One of the fundamental alloying elements, nickel provides such properties as deep hardening, improved toughness at low temperatures, good resistance to corrosion when used in conjunction with chromium in stainless grades, and ready response to economical methods of heat-treating.

Chromium—This element is used extensively to increase the corrosion-resistance of steel. It also improves the surface-resistance to abrasion and wear. It exerts a toughening effect and increases the hardenability.

Molybdenum—This element exerts a strong effect on the hardenability and toughness of steel. It greatly increases resistance to short-time and long-time stress at high temperatures.

Vanadium—An element used to refine the grain and enhance the mechanical properties of steel.

A combination of two or more of these alloying elements usually imparts some of the characteristic properties of each. For example, chromium-nickel grades of steel develop good hardening properties with excellent ductility. And chromium-molybdenum steels develop excellent hardenability with satisfactory ductility and a certain amount of heat-resistance. In other words, the total effect of a combination of alloying elements is usually greater than the sum of their individual effects. This interrelation must be taken into account whenever a change in a specified analysis is evaluated.

The four elements mentioned above, as well as others, will be discussed at greater length in subsequent pages. Let us begin with a very important agent, manganese.

Manganese

A common and economical alloying agent, manganese is both highly respected and highly essential.

It is one of the most basic elements in alloy and carbon steels; in fact, all analyses contain manganese to some extent. Whenever the content exceeds 1.65 pct, manganese steels are classed as alloy steels.

Manganese is one of the energetic deoxidizers, and has less tendency to segregate within the ingot than most other common elements. It is quite beneficial to surface quality in all carbon ranges and minimizes "red shortness" or susceptibility to tearing and cracking at rolling temperatures.

Manganese contributes markedly to strength and hardness, but to a lesser degree than carbon. Actually, the effectiveness of manganese in this respect depends largely upon the carbon content, for higher-carbon steels are more affected by manganese than are the lower-carbon steels.

Another function of manganese is to decrease the minimum — or critical — cooling rate. In this connection it enhances the hardenability. As might be expected, high manganese content with increasing carbon has a tendency to lower both ductility and weldability.

Fine-grained manganese steels attain unusual toughness and strength. Such steels are often used in the making of gears, spline shafts, automobile axles, steam valves, rifle barrels, cylinders for compressed gas, and many other products. With a moderate amount of vanadium added, manganese alloy steels are also used for forgings too large to be liquid-quenched properly.

Silicon

Silicon is a very abundant nonmetallic element, one of the chief elementary constituents of the earth's crust. In the form of ferrosilicon, it is used by steelmakers as a deoxidizer and hardener in both alloy and carbon steels.

When the maximum silicon content is specified within the limits of 0.60 to 2.20 pct, the resulting steel is classed as a silicon alloy steel. However, all other standard alloy grades are specified to a range of 0.20 to 0.35 silicon for purposes of deoxidation. Silicon has several interesting effects, among them three that should be noted carefully: (1) it raises the critical temperature for heat-treatment; (2) as the amount is increased, it increases the susceptibility of steel to decarburization and graphitization; (3) combined with other alloying elements such as nickel, chromium, and tungsten, it promotes resistance to high-temperature oxidation.

SILICON-MANGANESE STEELS

Of the alloy steels relying heavily on silicon, one of the most important groups is the silicon-manganese series. As mentioned above, silicon is recognized as a deoxidizing agent, and a powerful one. Manganese behaves in the same manner but to a lesser degree.

Manganese exerts beneficial effects on the mechanical properties of heat-treated steel. Silicon as an alloy increases the strength. A properly balanced combination of the two elements produces a steel with unusually high strength, and with good ductility and shock-resistance.

Silicon-manganese steel has been widely used for the making of coil and leaf-type springs. It has also been used successfully for chisels, drift pins, punches, shear blades, mine bits, and other products that must be shock-resistant. It responds readily to oil-quenching, and when tempered at the correct temperature, it possesses not only shock-resistance but toughness and strength.

Nickel

Each element in an alloy steel has its own particular job to do, and each is included with a special purpose in mind. What are some of the reasons, say, for using nickel, chromium, molybdenum, vanadium, and other components that appear in the various analyses? The elements in any alloy steel work both individually and as a team. What does each one do?

Previous discussions have been devoted to the functions of manganese and silicon. In this one we shall try to answer some questions relating to nickel, one of the fundamental alloying elements.

Nickel increases toughness and resistance to impact, particularly at low temperatures; lessens distortion in quenching; improves corrosion-resistance. It lowers the critical temperatures of steel and widens the temperature range for successful heat-treatment.

Nickel steels are particularly suitable for case-hardened parts, such as aircraft-engine gears and roller bearings. Such steels provide strong, tough, wear-resistant cases and also ductile core properties.

Advantages imparted by nickel are not restricted to quenched-and-tempered steels. Nickel often permits given strength levels to be obtained at considerably lower carbon contents, thereby markedly increasing toughness, plasticity, and fatigue-resistance. Nickel steels are therefore highly suitable for applications where liquid quenching is not employed, such as high-strength structural steels used in the as-rolled condition or heavy forgings not adapted to quenching. Products of this nature must develop superior properties after nothing more severe than air-quenching treatments.

Chromium

As previously pointed out in this series, the elements that together make up an alloy steel work both singly and collectively. In a sense they are like the components of a machine, each having its job to do, yet each working with other components to achieve an overall result.

Chromium is a versatile agent. Among other things, it fosters depth-hardenability, improves surface resistance to abrasion and wear, and promotes carburization. Of the common alloying elements, chromium ranks near the top in hardenability. This property tends to make high-chromium steels relatively air-hardening; hence it is valuable in applications where, for one reason or another, liquid quenches are undesirable.

Chromium steels are relatively stable at high temperatures and are often used where resistance to heat is important. Moreover, the presence of chromium is a vital factor in helping to retard or prevent corrosion.

The uses of chromium steels are many and varied. Among the more familiar items that often contain chromium are hand tools, gears, springs, turbine wheels, ball and roller bearings, forged shafts and rotors, etc. There are of course numerous others; virtually no list would be all-inclusive.

Molybdenum

Molybdenum is a highly reliable performer in numerous types of analyses. Because of its many desirable properties, molybdenum is one of the most respected of all the alloying agents. It is often used in conjunction with chromium, manganese, nickel, cobalt, tungsten, vanadium, or various combinations of these elements.

Molybdenum promotes hardenability in steel, and is useful where close hardenability-control is essential. It increases depth-hardness and widens the range of effective heat-treating temperatures. Moreover, it has a strong tendency to form stable carbides that hamper grain-growth prior to quenching, thus making the steel fine-grained and unusually tough at the various hardness levels.

Another point in favor of molybdenum is its ability to increase the tensile and creep strengths of alloy steels at high temperatures. Still another is its talent for enhancing corrosion-resistance in high-chromium and chromium-nickel steels.

Among the familiar products that frequently contain molybdenum are high-speed cutting tools, forged crankshafts and propeller shafts, turbine rotors, high-pressure boiler plate, high-pressure cylinders, permanent magnets, and armor-piercing projectiles. This is by no means intended as a complete list, but rather as a few typical examples.

Vanadium

Though the beneficial effects of vanadium in alloy steels have been known for many years, the ore was at one time a comparative rarity. Vanadium is still rather expensive because of the care required in processing the ore; however, there are now ample supplies for present-day applications.

Vanadium is a highly valuable alloying agent. It is an extremely powerful deoxidizer, though seldom used primarily for that purpose. Vanadium also tends to form stable carbides in steel — carbides that do not go readily into solution when heated above the critical temperature for quenching. The grain-growth-inhibiting effect of vanadium promotes a fine-grained structure over a fairly broad quenching range, thus imparting strength and toughness to the heat-treated steel. Moreover, the carbides are not prone to agglomerate during the tempering operation.

Vanadium is used in constructional steels, not only to refine the grain, but to improve the mechanical-property balance. Generally speaking, the amount of vanadium in constructional steels ranges from approximately 0.03 to 0.25 pct, though larger quantities are required in tool steels and special analyses. A list of products containing vanadium would include certain types of spring steels, plates, gears, high-temperature steels; forged axles, shafts, and turbine rotors; and other items requiring impact- and fatigue-resistance.

Copper

One of the best known of all metals, copper certainly needs no introduction here. Its uses are legion. It is one of the best conductors of heat and electricity. It is popular with the housewife, essential to the engineer. But possibly not so well known is its very important function as an alloying element in certain types of steels. So used, copper increases resistance to atmospheric corrosion and also acts as a strengthening agent.

Since copper does not oxidize in the steel melt, it can be added at any time during the course of the heat. Pure copper melts at about 1980 deg F.

Copper is added to steel in varying amounts. The actual proportion, of course, depends upon the end product in mind. Some of the most widely used copper-bearing steels are those containing from 0.20 to 0.50 pct. In these, copper has been found to increase corrosion-resistance without materially affecting mechanical properties. It has been found, too, that paint frequently lasts longer on such steels than on the non-copper-bearing types.

Among the best known of the copper-bearing steels are the high-strength, low-alloy grades developed in recent years. Generally speaking, the ductility of steels in this group is comparable to that of conventional structural steel. The yield strength, however, is usually higher. Copper, working as a team with chromium, nickel, and phosphorus, substantially raises the level of corrosion-resistance in these steels; yet its presence does not adversely affect welding characteristics.

Aluminum

Aluminum as an element has been known to chemists and metallurgists for many years. It is never found in nature in its metallic state, being derived chiefly from bauxite, an aluminum hydroxide. Bauxite is present in various parts of the world, including several tropical and semitropical regions.

When used in the making of alloy steels, aluminum has several important functions. Because of its great affinity for oxygen, it is a reliable deoxidizer. It produces fine austenitic grain size. And when it is present in amounts of approximately 1 pct, it promotes nitriding. The nitriding process could be described as surface- or case-hardening by means of a nitrogenous medium, or by heating in an atmosphere of ammonia gas and dissociated ammonia mixed in proper proportions.

Other effective agents in producing nitrided cases are chromium, vanadium, tungsten, and molybdenum. As a rule, however, the hardest cases are obtained with aluminum-bearing steels, the nitriding grades being a good example. These are usually steels of medium carbon content with additions of chromium, molybdenum, and sometimes nickel.

Generally speaking, the lower the effective nitriding temperature, the harder the case will be. Aluminum-bearing steels usually show a case-hardness range of 950 to 1150 DPHN (diamond pyramid hardness number). Steels in which no aluminum is present have cases of substantially lower hardness.

Boron

Boron is a nonmetallic element of which this country has a plentiful supply. In its natural or unprocessed state it occurs only in combination, as in borax, etc. Pure boron is a gray, extremely hard solid with a melting point in excess of 4000 deg F.

This element is used in steel for one purpose only — to increase hardenability; that is, to increase the depth to which the steel will harden when quenched. Its effective use is limited to sections whose size and shape permit of liquid quenching. Only a few thousandths of 1 pct is ordinarily added, and boron steels are evaluated by increased hardenability rather than chemical content. A number of alloys, including several grades of ferroboron, are available for adding boron to steel.

Boron intensifies the hardenability characteristics of other elements present in the steel. It makes possible a considerable degree of alloy conservation when used with steels containing small amounts of alloying elements. However, since it readily oxidizes at high temperatures, some steelmakers prefer a melt with relatively low boron content and relatively high contents of other elements that protect the boron from oxidation.

It should be noted that boron is very effective when used with low-carbon alloy steels; but its effect is reduced as the carbon increases. When the carbon content is above 0.60 pct, the use of boron is not suggested, the exception being the "case" in those steels that are carburized.

Boron steels often require closer temperature control in heat-treatment than do some of the other alloy analyses; but aside from this they present no special problems. Their cold- and hot-working properties are considered at least equal to those of ordinary alloy steels. In cases where boron makes possible a lower alloy content, improved machinability frequently results.

Grain Size

The grain size of alloy steels is understood to mean austenitic or inherent grain size, as indicated by the McQuaid-Ehn carburizing test. Austenitic grain size should be distinguished from ferritic grain size, which is the size of the grains in the as-rolled or as-forged condition with the exception of those steels that are austenitic at room temperature.

When steel is heated through the critical range (approximately 1350 to 1600 deg F for most steels, depending on the composition), transformation to austenite takes place. The austenite grains are extremely small when first formed, but grow in size as the temperature above the critical range is increased, and, to a limited extent, as the time is increased. It is apparent, therefore, that both time and temperature must be constant in order to obtain reproducible results.

When temperatures are raised materially above the critical range, different steels show wide variations in grain size, depending on the chemical composition and the deoxidation practice used in making the heat. Heats are customarily deoxidized with aluminum, ferrosilicon, or a combination of deoxidizing elements.

Steels using aluminum or certain other deoxidizers in carefully-controlled amounts maintain a slow rate of grain growth at 1700 deg F, while heats finished with still other deoxidizers, usually ferrosilicon, develop relatively large austenitic grain size at temperatures somewhat below 1700 deg F.

The McQuaid-Ehn test is the one ordinarily used for determining grain size. Steel is rated with a set of eight ASTM charts that are compared one at a time with a specially-prepared steel sample until one is found to match. Number 1 grain size, the coarsest, shows 1½ grains per sq in. of steel area examined at 100 diameters magnification. The finest chart is Number 8, which shows 96 or more grains per sq in. at the same magnification.

PROPERTIES AFFECTED BY GRAIN SIZE

Fine-grain steels (grain sizes 5, 6, 7, and 8) do not harden as deeply as coarse-grain steels, and they have less tendency to crack during heat-treatment. Fine-grain steels exhibit greater toughness and shock-resistance — properties that make them suitable for applications involving moving loads and high impact. Practically all alloy steels are produced with fine-grain structures.

Coarse-grain steels exhibit definite machining superiority. For this reason a few parts which are intricately machined are made to coarse-grain practice.

How Heat-Treatment Affects Alloy Steels

Heat-treatment may be defined as an operation, or series of operations, involving the heating and cooling of steel in the solid state to develop the required properties. There are in general five different forms of heat-treatment used with alloy steels. These treatments modify the mechanical properties of the steel to suit the end use.

The five forms of treatment mentioned above, as applied to constructional alloy steels, are discussed in the following paragraphs.

(1) Normalizing is a form of treatment in which the steel is heated to a predetermined temperature above the critical range, after which it is cooled slowly to below that range in still air. The purpose of normalizing is to promote uniformity of structure and to alter mechanical properties.

(2) Annealing consists of heating the steel to a point at or near the critical range, then cooling it at a predetermined rate. Annealing may be used (a) to soften the steel; (b) to develop a particular structure, such as lamellar pearlite, or spheroidized-carbide; (c) to improve machinability, or to facilitate cold-shaping; (d) to prepare the steel for subsequent heat-treatment; (e) to reduce stresses; (f) to improve or restore ductility; or (g) to modify other properties.

(3) Quenching and Tempering usually consists of three successive operations:

(a) heating the steel above the critical range, so that it approaches a uniform solid solution;

(b) hardening the steel by quenching it in oil, water, brine, or fused salt bath; and

(c) tempering the steel by reheating it to a point below the critical range, in order to effect the proper combination of strength and ductility.

*(4) **Precipitation Hardening*** is accomplished by either *"quench aging,"* or *"strain aging." "Quench aging"* is the hardening that occurs in steel after rapid cooling from an elevated temperature. *"Strain aging"* is the hardening that occurs in steel after cold-working. Aging of structural alloy steels in the range of 65/70,000 psi Yield Strength, is accomplished by heating for approximately 2 to 4 hours at 1,000 deg to 1,125 deg F.

*(5) **Stress-Relieving*** is the process of reducing internal stresses by heating the steel to a temperature below the critical range, and holding for a time interval sufficient to equalize the temperature throughout the piece. The object of this treatment is to restore the elastic properties of the steel, or to reduce stresses that may have been induced by machining, cold-working, or welding.

Quenching Media

In the quenching of alloy steels, several points require consideration. Among them are the size and shape of the piece, the type of steel involved, the quenching medium, and proper agitation of the quenching bath.

The composition of the steel has an important bearing on the selection of a quenching medium. As an example: shallow-hardening steels require a fast cooling rate, whereas deeper-hardening steels require progressively slower rates as the alloy content increases.

Three commonly used types of quenching media for alloy steels are water, oil, and air. These are discussed below in the order of quenching severity:

*(1) **Water.*** Since shallow-hardening steels require fast quenching rates, water is the quenching medium used to harden them. Agitation is generally used to help in obtaining the desired cooling rate. The use of brine solutions has proven beneficial when sufficient agitation cannot be obtained. It should be noted that the quenching rate drops as water temperature is increased. The range of 70 deg to 100 deg F is recommended.

*(2) **Oil.*** An oil quench cools more slowly than water, and faster than air. Oil-hardening steels can be hardened with less distortion and greater safety than water-hardening steels. Mineral oils are generally used because of their low cost and relatively stable nature.

*(3) **Air.*** If sufficient alloying elements are present, critical cooling rates are decreased to the extent that certain steels can be quenched in either still or forced air.

While the choice of quenching medium is of prime importance, there is another factor that should not be overlooked. This is the agitation of the quenching bath. The more rapidly the bath is agitated, the more rapidly heat is removed from the steel, and the more effective the quench.

When Should Alloy Steels Be Ordered to Hardenability?

What is hardenability and how does it differ in carbon and alloy steels?

Hardenability can be defined as the capacity of steel to develop a desired degree of hardness, usually measured in depth. It is produced by special heating and cooling. Carbon steel, except in small sections, will normally harden to a depth slightly below its surface, while alloy steel can, under certain conditions, harden uniformly through its entire cross-section.

Surface hardness obtainable after quenching is largely a function of the carbon content of the steel. Depth hardness, on the other hand, is the result of alloying elements and grain size, in addition to the carbon present in the steel.

In general, where hardenability is the prime consideration, it is not too important which alloy steel is used, just as long as there is sufficient carbon present to give the prescribed hardness, and enough alloying elements to quench out the section. It is not considered good practice to alloy a small section excessively, since excessive use of alloying elements adds little to the properties and can, in some instances, induce susceptibility to quenching cracks.

There are, of course, numerous cases where factors other than hardenability must be considered; such factors as low-temperature impact, heavy shock, creep-resistance, and the ability to resist temper brittleness. Through-hardening, therefore, is not always desirable. For example, shallow hardening is often necessary in shock applications, because a moderately soft core is essential.

Determining Depth-Hardness

The hardenability of an alloy steel is usually measured by the depth to which the steel will harden under specific conditions of heating and cooling. One of the most conclusive methods of determining depth hardness is the end-quench hardenability test (ASTM A255). In essence, this test is as follows:

A 1-in. round specimen, approximately 4 in. long, is heated uniformly to the proper quenching temperature. The specimen is removed from the furnace and placed in a bracket; then a jet of water at room temperature is played on the bottom face of the specimen without touching the sides. This water jet is kept active until the entire specimen has cooled. Longitudinal flat areas are ground on opposite sides of the piece, and Rockwell C readings are taken at 1/16-in. intervals. The resulting data are plotted on graph paper, with the Rockwell C values as ordinates and distances from the quenched end as abscissae.

Experiments have shown that the points on the hardenability curve approximate the cooling rates at the centers of quenched rounds of various sizes; and that the hardness values at the centers of these rounds will correspond very closely with those shown at points on the end-quench hardenability curve.

In general it may be said that when end-quench curves for different steels approximately coincide, these steels can be treated similarly for equivalent tensile properties in sections of the same size.

A study of hardenability curves reveals that depth-hardness depends upon the amount of carbon present, the alloy content, and the grain size. Manganese, chromium, and molybdenum are the chief elements that promote depth-hardness, while nickel and silicon help to a lesser degree. It should be noted, also, that phosphorus promotes depth-hardness, while sulphur has a negative effect. In normal low-phosphorus and low-sulphur steels, the two elements neutralize each other.

Carburizing

Carburizing is a means of impregnating the surface of steel with carbon, usually to very limited depths. Its purpose is to provide a hard, wear-resisting "case," or outer shell. Alloy steels, correctly handled, can be case-hardened without sacrificing desirable core properties.

There are three types of carburizing in general use. Briefly, they are:

Liquid Carburizing—The medium here is a hot salt bath composed basically of cyanide compounds. The steel is immersed in the bath, the period of immersion depending upon the analysis of the steel and the depth of case desired. Liquid carburizing is a convenient method of producing thin, hard, wear-resisting cases, generally within the depth range of 0.02 to 0.03 in. However, deeper cases may be obtained, the actual depths depending upon economics and end uses.

Gas Carburizing—This method employs a furnace in which a carbonaceous atmosphere is created; i.e., gases that are high in carbon components, or those containing carbon. Steel subjected to gas carburizing can be case-hardened to depths generally ranging from 0.01 to 0.04 in. When quenching takes place immediately after carburizing, distortion can be kept to a minimum.

Pack Carburizing — Where the pack method is used, the parts to be carburized are buried in a container of dry carbonaceous materials. The container is sealed tight to prevent the infiltration of air, placed in a furnace and kept there for eight hours or more, the actual time depending upon the depth of case desired. Pack carburizing is particularly suitable where a deep case is essential (0.06 in. and over), although medium cases in the 0.04-to-0.06-in. range are possible.

Determining Proper Depth of Case

In the previous article of this series we discussed the carburizing of alloy steels, pointing out that the purpose of carburizing is to provide a hard, abrasion-resistant outer shell or "case." Such a discussion naturally gives rise to the question, What factors influence the choice of case? Should it be shallow? Medium? Deep or extra-deep?

While it is not always wise to formulate hard-and-fast rules, the following may be used as a general yardstick:

Shallow cases (less than 0.02 in.). Suitable where wear-resistance alone is the chief requirement, and where good surface condition after heat-treating is advantageous. Not suitable if high stresses are apt to be encountered in service.

Medium cases (0.02 to 0.04 in.). For high wear-resistance. Will stand up under substantial service loads and stresses. The thickness is sufficient to permit certain finishing operations, such as light grinding.

Medium-to-deep cases (0.04 to 0.06 in.). For high wear-resistance. A case in this depth range is essential where continuing friction is involved, especially friction of an abrasive or semi-abrasive nature. It is also a good precautionary measure where application of the finished part may sometimes involve crushing action.

Extra-deep cases (more than 0.06 in.). Cases of this depth can be obtained by extending the furnace time in pack carburizing. Highly wear-resistant, extra-deep cases also withstand shock and impact. A large camshaft of an internal-combustion engine is a good example of a part requiring the extra-deep case. This is especially true of the cam lobes themselves.

Flame-Hardening

The process known as flame-hardening involves the direct application of flame to the surface of steel, heating it above the transformation range, then hardening it by quenching. The primary purpose of this process is to achieve surface-hardness without affecting core properties. Jets of flame are played directly on the steel, and hardness penetration can be made to vary considerably. Usually in alloy steels this depth will range from 0.03 to 0.12 in., the actual figure depending upon the method of heating and quenching used.

Unlike carburizing, flame-hardening does not involve the absorption of extraneous elements by the steel. There is no alteration of the chemical composition. To put it simply, the steel must have its own self-hardening characteristics; cannot be dependent upon carbonaceous salt baths, gases, and other media.

Flame-hardening is not a substitute for the conventional furnace method. Each has its uses. The particular virtue of flame-hardening is that the flames can be directed to localized areas. The furnace, on the other hand, is generally more economical and feasible when parts produced in large quantities must be hardened all over.

Any type of hardenable steel, alloy or carbon, can be flame-hardened, and there will usually be no scale or pitting. The alloy content is the governing factor when determining the quench. In some cases a rapid quench is required; in others, it can be as slow as air-cooling. Tempering presents no problems, for flame-hardened steel can be tempered as if hardened to the same point by other methods.

A list of typical flame-hardened parts would include such familiar items as gear and sprocket teeth, and certain types of cams and rollers, shoe treads. A complete list would include many other parts that often require a localized hardening treatment, especially for wear-resistance.

Tests for Determining Mechanical Properties

The types of tests used to evaluate the mechanical properties of an alloy steel depend upon the end use of the steel involved. Generally speaking, mechanical properties are determined by tension, bend, and hardness tests, and by a group of special tests employed on tubular and wire products. Briefly, they are:

(1) Tension tests provide means of determining tensile strength, yield point, yield strength, proof stress, proportional limit, per cent elongation, and per cent reduction of area. This sort of test subjects the steel to stresses resulting from the application of an axial tensile load to the specimen ends, the load being sufficient to rupture the specimen.

(2) Bend tests often aid in determining the ductility of steel. The severity of such a test depends largely upon the bending radius used. Several factors influence the length of radius, including thickness of the test specimen, width of test specimen, direction of test, chemical composition, tensile strength of specimen, etc.

(3) Hardness tests determine the steel's resistance to penetration. This characteristic is most commonly measured by the Brinell Test or the Rockwell Test. In the former, pressure is applied to the surface of a test specimen by means of a ball 10 mm in diameter. Two diameters of the resulting impression are measured and averaged, the average is converted to the hardness number by means of a conversion table. In the Rockwell Test, the degree of hardness is read on a gage; hardness is measured by the penetration of a diamond point or a 1/16-in. steel ball. Rockwell "C" scale readings are used in connection with the diamond point; "B" scale in connection with the steel ball. The "C" and "B" are the most commonly used of the several Rockwell scales.

(4) Special additional tests are often made on tubular and wire products. These include such items as hydrostatic and manipulating tests, and torsion and wrapping tests, the latter two being used only with wire.

How Alloy Steels Respond to Induction Hardening

In the now-popular induction-hardening process, steel is first heated above the transformation range by means of electrical induction, then quenched as required. Special equipment is needed, and heat is developed as follows:

High-frequency alternating current passes through a coil or inductor, with the result that a magnetic field is created in the coil. When the piece to be treated is placed in this field, it is heated rapidly by induced energy. With the various types of induction-heating equipment, the process is capable of surface- or case-hardening to various controlled depths; however, through-hardening can be obtained with certain alloy steels. Ferrous metals that respond well to induction hardening include numerous grades of both alloy and carbon steels, as well as hardenable stainless steel and plain or alloyed cast iron.

As a rule, when alloy steels which contain non-carbide-forming elements, such as nickel, are heated by induction, the usual hardening temperatures can be used. But with alloy steels that do contain carbide-forming elements such as chromium, molybdenum, and vanadium, the hardening temperature must be increased if the normal effect of the alloying elements is desired.

Hardness obtained by the induction process is a function of the carbon content and prior structure, just as it is when conventional heating methods are used. Nevertheless, higher surface-hardness values for a given carbon content have often been noted in parts subjected to surface induction-hardening. The extra hardness may be as much as five Rockwell C points for steels of 0.30 pct carbon.

As pointed out previously, the induction method requires special equipment. However, it possesses several marked advantages, including speed of heating and cleanliness of operation. Pieces heated by induction are usually subject to a minimum of scaling and distortion. Moreover, induction-hardening equipment is very compact and therefore conserves floor space.

Normalizing Alloy Steels

There are several forms of heat-treatment commonly employed in the processing of alloy steels. Each in its own way modifies the mechanical properties and structures of steel, and each is chosen with a definite objective in mind. The five usual forms of treatment are normalizing, annealing, spheroidize-annealing, quenching and tempering, and stress-relieving.

In this particular discussion, let us consider briefly the purposes and effects of normalizing.

Normalizing is an operation in which the steel is heated to approximately 100 deg F above the upper transformation range, then cooled in still or agitated air. The basic purpose is to refine the prior structure produced by variations in finishing temperatures encountered in rolling or forging. The structure resulting from normalizing, being more uniform, will help create improved mechanical properties when the steel is subsequently reheated, liquid-quenched, and tempered.

There are times when large steel parts (heavy forgings, for example) cannot be liquid-quenched because of their size. In cases of this nature, the heat-treatment must consist of single or multiple normalizing followed by tempering.

High-temperature normalizing is sometimes used for grain-coarsening low-carbon alloy steels to promote machinability. (In high-temperature normalizing, steel is heated to more than 100 deg F above the upper transformation range.) At times it is possible to machine a steel in the air-cooled condition, the governing factor being the alloy content. However, the highly alloyed analyses may require annealing or tempering after normalizing, to decrease the hardness.

It is essential, when normalizing is employed, that free circulation of still or agitated air be provided. When air-cooling of individual bars or forgings is not practicable, the furnace charge should provide for some means of separation, such as racks or spacers.

Annealing: Its Uses with Alloy Steels

Broadly speaking, the primary purpose of annealing is to soften steel and make it more workable. Annealing, as applied to alloy steels, may be defined as a process that heats above, and furnace-cools through, the critical range at a controlled, specified rate of speed; or that heats to a point within, and furnace-cools to a point below, the critical range. In either case, the choice depends upon the structure and maximum hardness desired.

The first method produces a lamellar pearlitic structure, while the second creates a spheroidized condition. These will be discussed separately in the following paragraphs:

(1) Lamellar pearlitic structure. It should be mentioned at once that this structure can be obtained both as described above and by a modified method known as isothermal annealing. In the isothermal process, the steel is heated above the critical temperature (austenitized), then transformed at a predetermined temperature, which depends upon the analysis. This operation requires two furnaces or salt baths — one for austenitizing, one for transformation.

Lamellar pearlitic structures are generally associated with machinability in carbon ranges from 0.20 to 0.60 pct, provided the hardness does not exceed the optimum maximum Brinell numeral. This is especially true where critical tooling is involved. It is a very versatile structure, as it gives best results in such operations as broaching, tapping, threading, deep drilling, boring, milling, and tooling as applied on single- and multiple-spindle bar automatic machines.

(2) Spheroidized structure. There are two general fields of use for this type of structure when alloy steels are employed. In the low and medium carbon ranges, spheroidization is necessary for cold-shaping operations, such as heading, extruding, drawing. In the higher carbon ranges (over 0.60 pct), it is mandatory where machining is involved, because it tends to lower the hardness of the steel.

Quenching and Tempering

Of the various methods of heat-treating alloy steels, the most important is that involving quench and temper. This method, which enhances the mechanical properties of the end product, differs materially from normalizing and annealing (pages 26 and 27).

The purpose of quenching is to effect a cooling rate sufficient to develop the desired hardness and structure.

Before quenching takes place, steel is heated to a point above the transformation range. Quenching is the subsequent immersion of this heated steel in a circulated or agitated bath of oil, water, brine, or caustic; or, in the case of austempering or martempering, generally in agitated molten salt baths. Austempering and martempering are preferable where a minimum of distortion is desired.

Quenching *increases* the tensile strength, yield point, and hardness of alloy steels. It *decreases* ductility — that is, elongation and reduction of area. It also decreases resistance to impact. However, by means of tempering, it is possible to restore some of the ductility and impact-resistance — but only at a sacrifice of tensile strength, yield point, and hardness.

The results of mild oil- or water-quenching as related to mass effect can be found in the end-quench hardenability test. Voluminous data concerning this test are issued by AISI and SAE in the form of hardenability bands for the various grades of alloy steels.

If thermal cracking is to be avoided, cooling by liquid quenching should not be carried to a point below 150 deg F. When a temperature of 150 deg F is approached, immediate tempering should follow. Because of residual stresses, no steel should be used in the as-quenched condition.

Tempering can be defined as reheating to a specified temperature below the lower critical range, followed by air cooling. It can be done in furnaces, oil, or salt baths, the temperatures varying from 300 to 1200 deg F. With most grades of alloy steel, it is best to avoid temperatures between 500 and 700 deg because of the "blue brittleness" that occurs in this range. Maximum hardness and wear-resistance result from tempering at low temperatures; maximum toughness is achieved by tempering at the higher levels. Of course, one of the essential reasons for tempering is to relieve the residual stresses set up in quenching.

Thermal Stress-Relieving

In the production of alloy steel bars and parts made of alloy steel, stresses are sometimes set up, and these stresses must be relieved before optimum results can be expected. Two general types of stress-relieving are practiced — thermal and mechanical. In this discussion we shall consider only the former.

There are several important reasons for thermal stress-relieving. Among these are the following:

(1) The first and most fundamental purpose is to reduce residual stresses that might prove harmful in actual service. In the production of quenched and tempered alloy steel bars, machine-straightening is necessary. This induces residual stresses in varying degrees. Bars are usually stress-relieved after the straightening operation. When the bars are subjected to later processing that sets up additional stresses, subsequent stress-relieving may be necessary.

(2) A second major purpose of thermal stress-relieving is to improve the dimensional stability of parts requiring close tolerances. For example, in rough-machining, residual stresses are sometimes introduced, and these should be relieved if dimensional stability is to be assured during the finish-machining.

(3) Thermal stress-relieving is also recommended as a means of restoring mechanical properties (especially ductility) after certain types of cold-working. Moreover, it is required by the "safe-welding" grades of alloy steels after a welding operation has been completed.

Alloy bars are commonly stress-relieved in furnaces. Temperatures under the transformation range are employed, and they are usually in the area from 850 deg to 1200 deg F. The amount of time required in the furnace will vary, being influenced by grade of steel, magnitude of residual stresses caused by prior processing, and mass effect of steel being heated. After the bars have been removed from the furnace, they are allowed to cool in still air to room temperature.

In the case of quenched and tempered alloy bars, the stress-relieving temperature should be about 100 deg F less than the tempering temperature. Should the stress-relieving temperature exceed the tempering temperature, the mechanical properties will be altered.

Items other than bars (parts, for example) can be wholly or selectively stress-relieved. If the furnace method is used, the entire piece is of course subjected to the heat; selective relieving is impossible. However, if a liquid salt bath or induction heating is used, the piece can be given overall relief or selective relief, whichever is desired.

Cold-Finishing of Alloy Steels: The Cold-Drawing of Bars

Cold-finishing of alloy bars may be divided into two general categories: (1) cold-drawing, where the bars are pulled through a die with no surface removal; and (2) turning and grinding, which removes the surface. We shall consider the cold-drawing procedure in this discussion.

Cold-drawing is the process of pulling a pickled and limed bar through a die, which results in a bright, smooth finish of the section, combined with close tolerances. The alloy bars are prepared for cold-drawing by pickling in a hot solution of dilute sulphuric acid for removal of scale. This is followed by a water rinse, and immersion in a hot lime-water bath to neutralize the effects of the acid, and to aid in carrying special liquid lubricants into the die.

Alloy bars may be cold-drawn under four conditions: *as-rolled*, *normalized* (low-carbon grades only), *annealed* (lamellar or spheroidized), or *quenched and tempered*. These conditions are determined by the grade of alloy steel, the resultant hardness, and the mechanical properties desired for a given end use.

In cold-drawing, the alloy bar is machine-pointed, to reduce the size at one end so it will pass easily into the die opening. Otherwise, the bar is pushed or extruded into the die by an auxiliary device. A die-holder, which can be made to contain from one to four dies, is mounted in an appropriate head assembled across a "draw bench," so that from one to four bars can be drawn at the same time. The draw bench has a bed which accommodates a 4-wheel buggy with jaws that grip the pointed ends of the bars as they emerge from the dies. The buggy has a hook on one end which engages an endless chain, thus pulling the bars through the dies for their entire length.

After cold-drawing, each bar feeds automatically into a straightening machine, and is sheared or "cracker-cut" to length on appropriate machines. Saws are used when the cross-sections of the bars are too large to be cracked or sheared, or when clean square ends are required.

Smaller sizes in the form of coils are drawn on "bull-blocks," or "wire-blocks," depending on sizes, followed by straightening and cutting on special machines.

Cold-Finishing of Alloy Steels: The Effect of Cold-Drawing

During the cold-drawing process, certain changes take place in the steel structure, and in mechanical properties. There is a slight increase in tensile strength, compared with a substantial increase in yield point, and a decrease in ductility. These properties enable the production of small parts which require the greater strength necessary for certain automatic-machine forming operations, and a machine finish superior to hot-rolled material. Naturally, the beneficial effects of alloy steels are attained in the subsequent heat-treatment of parts.

The process of cold-drawing results in bars which are accurate to shape, and within close tolerances. These conditions are ideal for automatic machining, as the elimination of scale by pickling is conducive to long tool life, and the accuracy of shape and close tolerances permit the bars to pass freely through the feed mechanism of the "automatic." Moreover, the cold-drawn finish and tolerances may be such that machining can be eliminated in some areas of the finished part. For example, sparkplug shells are produced from hexagon bars which have no machining done on the hexagon sections.

Continuous roller hearths and car-bottom furnaces of both standard and controlled-atmosphere types are used for special treatment of alloy bars before cold-drawing. Thermal stress-relieving (discussed on page 29 of this booklet) can be used to reduce residual stresses in the steel caused by the cold-drawing process, wherein the mechanical properties will be altered depending upon the temperature used.

Cold-Finishing of Alloy Steels: Turning and Polishing

In both the turning and grinding operations, adequate allowances provide for the removal of decarburization and surface defects which sometimes occur in alloy bars.

As previously stated, the outstanding advantage of cold-drawn bars over hot-rolled bars is the *bright, smooth finish.* However, the quality of the cold-drawn finish varies with the size and amount of draft (reduction of cross-sectional area) applied in cold drawing. For example, by using a 1/16-in. draft, a 3/4-in. round would have a better cold-drawn finish than a 3-in. round.

When a superior mirror-like finish with additional accuracy is required on surfaces that are not machined (such as on shafting or machine parts), two processes other than cold-drawing are suggested: turning and polishing, and grinding and polishing. The first of these will be discussed here.

CENTERLESS BAR TURNING

This method of cold-finishing is generally associated with centerless bar-turners, accommodating rounds from 1-1/4 in. to 6-in. diam, inclusive. The process is the reverse of conventional lathe-turning, which is normally used for larger sizes. The centerless turning equipment uses two cutter heads which contain from one to four cutting tools. The system provides for both rough and finish cuts. The bar, which is stationary, is fed horizontally into the rotary cutter heads by means of a mechanical or hydraulic feeding mechanism. Most bar-turners are equipped with a series of polishing rolls that also rotate around the bar as it feeds from the rotary cutter heads. This, combined with subsequent burnishing action from the straightening rolls, imparts a high degree of polished finish to the product. A polished surface on a turned bar can also be produced by a number of passes through the straightening rolls.

This process is applicable to normalized, annealed, or heat-treated carbon and alloy bars. It does not materially affect the mechanical properties. For this reason, the end product can be machined unsymmetrically, with little or no tendency to warp.

Cold-Finishing of Alloy Steels: Grinding and Polishing

Grinding and polishing of cold-drawn or turned alloy steel bars is the concluding discussion on the subject of cold-finishing. In the processes of turning and polishing, and grinding and polishing (both of which require removal of surface metal), the surface finish of the bars, as well as their dimensional accuracy and alignment, are improved. But the ultimate in quality of bright, smooth surface finish and accuracy is produced by grinding and polishing of either cold-drawn bars or turned bars up to 4-in. diam, inclusive.

CENTERLESS GRINDING

Sizes up to and including 4-in. diam, are generally confined to centerless cylindrical grinders. Larger sizes are ground on centers. A centerless grinder includes a grinding wheel, a regulating wheel for applying pressure against the bar, and a work-rest blade which both supports the bar and guides it between the wheel spacing. Automatic feed of the whole length of the bar is accomplished because the regulating wheel is set at an angle of inclination with respect to the grinding wheel, and thus within this system the bar rotates and feeds during grinding. The bar is then polished to a mirror-like finish by passing through straightening rolls.

Both processes of turning and polishing, and grinding and polishing, are applicable to normalized, annealed, or heat-treated carbon and alloy bars. These operations do not materially affect the mechanical properties. For this reason, the end product can be machined unsymmetrically, with little or no tendency to warp.

Evaluation of Machinability of Alloy and Carbon Steels

To produce a useful part, most steel has to be shaped by one or more of the metal forming methods. One of these is metal cutting or machining, which changes the shape, size, or finish of a workpiece.

Alloy or carbon steels are often received from the mill in the raw form of bars, forgings, or castings. The steel is placed in a suitable machine, such as a lathe, multiple-spindle automatic bar machine, drill press, milling machine, or one of a number of other types. Metal is then removed from the steel stock until it has acquired the desired shape. This is accomplished by causing motion to take place in the sharp-edged cutting tool, or the piece of steel, while they are held in contact with each other. Cutting tools, such as drills, tool bits, milling cutters, and the like, are made from highly-alloyed steel (tool steel), cast alloys, sintered carbide, or even ceramic material.

During machining, the metal is removed in the form of chips which may be of any length, from the short, well-broken type, to the long, stringy and continuous variety — depending upon the nature of the steel, the shape or geometry of the cutting tool, the speed and feed at which the cutting is done, and the coolant or cutting fluid applied.

"Machinability" of steel refers primarily to the ease with which it can be reduced to its final shape. It is measured by the speed and feed at which it can be cut, the quality of the surface finish produced, the length of time the tools will last, and the kind of chip formed in cutting. In a "free-machining" grade of steel, for example, high speeds and feeds can be used, tools will stand up well, surface finish will be good, and chips well broken.

Machinability is evaluated by the number of pieces having a satisfactory finish, within the required dimensional tolerances, that can be produced in a shift, or a day, with adequate tool life.

It can be appreciated that the study of the cutting of metals involves a large number of variables. These may be grouped in the following way:

(1) Steel Analysis (Process, composition, microstructure, and mechanical properties)

(2) Machine Tool (Condition, tool accessories, range of cutting speeds and feeds with ample power, etc.)

(3) Type of Machining Process (Turning, milling, forming, broaching, etc.)

(4) Cutting Condition (Speeds, feeds, and depth of cut)

(5) Cutting Tool (Composition, treatment, hardness, size, shape, grinding and surface finish)

(6) Cutting Fluid (Characteristics, application, and volume)

From this number of complex factors, laboratory tests and investigations have developed experimental data by using single variables, such as steel analysis, tool analysis, tool shapes, and cutting fluids. This information has proved to be a useful guide when combined with industrial experience; for no test method by itself has yet been developed that will include all the characteristics of a specific single- or multiple-machining operation.

The Effect of Lead in Alloy Steels, PART I

The subject of leaded alloy steels is discussed in two parts. Here we deal with basic definition, the reasons for excellent machinability, and the purpose of closely controlling the lead additive. Part II, which follows, touches upon working properties, and discusses when leaded alloy steel should be used.

WHAT IS A LEADED STEEL?

A leaded steel is any steel, carbon or alloy, to which lead has been added to improve its machining characteristics. This lead additive, generally held within the limits of .15 to .35 per cent, may be added to any standard AISI or SAE steel. The percentage of lead does not, to any practical degree, alter the mechanical properties of the base steel.

HOW LEAD IMPROVES MACHINABILITY

Theoretically, lead has an inherent self-lubricating action which reduces friction at the tool-chip interface. This permits appreciably higher cutting speeds and feeds because leaded steels have a lower coefficient of friction than non-leaded steels. Also, because of the finely dispersed lead particles, there are minute interruptions within the matrix which cause a premature breaking of chips. This minimizes build-up within the tool-chip interface, prolonging tool life and improving machined finishes.

Optimum cutting speeds are commonly increased by 25 to 40 per cent. Sometimes, depending upon the condition and grade of steel and the type of machining, these speeds can be more than doubled.

LEAD ADDITION MUST BE CLOSELY CONTROLLED

Lead is distributed throughout the ingot by the addition of pure metal shot. It is forced into the molten-steel stream during teeming (pouring from the ladle to the mold) by means of a fixed air-pressure gun. The lead shot, having a higher specific gravity than the molten steel, tends to segregate at the bottom of the ingot. This is controlled by pouring a predetermined amount of steel in the ingot prior to the lead addition.

Since the uniform distribution of lead is all-important to the machining properties of leaded alloy steels, steelmakers should exercise great care in (1) controlling the lead content through checking by the fluorescent X-ray method, and (2) inspection of billet specimens for lead distribution by means of exudation tests.

The Effect of Lead in Alloy Steels, PART II

This discussion touches upon working properties of leaded alloy steels and when their use should be considered.

WHAT ARE THE MECHANICAL AND WORKING PROPERTIES OF LEADED STEELS?

The mechanical properties of an alloy steel are determined principally by its basic chemical composition. The addition of lead in the specified quantity and with uniform distribution does not change this composition, and hence does not alter the mechanical properties to any appreciable degree. This is because lead retains its elemental form and does not alloy with the steel.

It follows that leaded alloy steel will roll, forge, bend, form, draw, etc., in the same manner as does the base alloy steel. It can also be torch-cut, welded, brazed, or heat-treated, again as determined by the working properties of the base steel.

Care must be exercised, however, during any operation which involves heating. The heating operation should be in a well-ventilated area so as to avoid any chance of the lead vapor concentrating in the atmosphere to create a health hazard.

WHEN SHOULD LEADED ALLOY STEEL BE USED?

Leaded alloy steels may be used in all types of machining operations to attain increased production and longer tool life, in comparison with non-leaded steels.

The advantage of leaded steel becomes more and more positive as the amount of machining required for the individual piece increases. Ordinarily, it takes a job that requires at least 25 per cent chip removal before leaded alloy steels become economical. This type of job is usually characterized by machining operations which require high rates of metal removal.

Another point to consider before making the decision to use leaded alloy steels is whether the speed of the machine tool can be increased. This is no problem for a relatively new machine, but older machines have a definite limit which may be below the speed needed to take full advantage of the superior machining properties of leaded alloy steels.

Forged parts, too, often require extensive machining after the forging operation, and might, therefore, be manufactured more economically from leaded alloy steel.

ALLOY STEELS (As of July, 1958)

STANDARD STEELS

OPEN HEARTH AND ELECTRIC FURNACE ALLOY STEELS BARS, BILLETS, BLOOMS AND SLABS

The ranges and limits in this table apply to steel not exceeding 200 sq in. in cross-sectional area.

	Chemical Composition Ranges and Limits, per cent								Corresponding SAE Number
AISI Number	C	Mn	P Max.	S Max.	Si	Ni	Cr	Mo	
1330	0.28/0.33	1.60/1.90	0.040	0.040	0.20/0.35	—	—	—	1330
1335	0.33/0.38	1.60/1.90	0.040	0.040	0.20/0.35	—	—	—	1335
1340	0.38/0.43	1.60/1.90	0.040	0.040	0.20/0.35	—	—	—	1340
1345	0.43/0.48	1.60/1.90	0.040	0.040	0.20/0.35	—	—	—	1345
3140	0.38/0.43	0.70/0.90	0.040	0.040	0.20/0.35	1.10/1.40	0.55/0.75	—	3140
E3310	0.08/0.13	0.45/0.60	0.025	0.025	0.20/0.35	3.25/3.75	1.40/1.75	—	3310
4012	0.09/0.14	0.75/1.00	0.040	0.040	0.20/0.35	—	—	0.15/0.25	4012
4023	0.20/0.25	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.20/0.30	4023
4024	0.20/0.25	0.70/0.90	0.040	0.035/0.050	0.20/0.35	—	—	0.20/0.30	4024
4027	0.25/0.30	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.20/0.30	4027
4028	0.25/0.30	0.70/0.90	0.040	0.035/0.050	0.20/0.35	—	—	0.20/0.30	4028
4037	0.35/0.40	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.20/0.30	4037
4042	0.40/0.45	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.20/0.30	4042
4047	0.45/0.50	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.20/0.30	4047
4063	0.60/0.67	0.75/1.00	0.040	0.040	0.20/0.35	—	—	0.20/0.30	4063
4118	0.18/0.23	0.70/0.90	0.040	0.040	0.20/0.35	—	0.40/0.60	0.08/0.15	4118
4130	0.28/0.33	0.40/0.60	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4130
4135	0.33/0.38	0.70/0.90	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4135
4137	0.35/0.40	0.70/0.90	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4137
4140	0.38/0.43	0.75/1.00	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4140
4142	0.40/0.45	0.75/1.00	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4142
4145	0.43/0.48	0.75/1.00	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4145
4147	0.45/0.50	0.75/1.00	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4147
4150	0.48/0.53	0.75/1.00	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15/0.25	4150
4320	0.17/0.22	0.45/0.65	0.040	0.040	0.20/0.35	1.65/2.00	0.40/0.60	0.20/0.30	4320
4337	0.35/0.40	0.60/0.80	0.040	0.040	0.20/0.35	1.65/2.00	0.70/0.90	0.20/0.30	4337
E4337	0.35/0.40	0.65/0.85	0.025	0.025	0.20/0.35	1.65/2.00	0.70/0.90	0.20/0.30	—
4340	0.38/0.43	0.60/0.80	0.040	0.040	0.20/0.35	1.65/2.00	0.70/0.90	0.20/0.30	4340
E4340	0.38/0.43	0.65/0.85	0.025	0.025	0.20/0.35	1.65/2.00	0.70/0.90	0.20/0.30	E4340
4422	0.20/0.25	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.35/0.45	4422
4427	0.24/0.29	0.70/0.90	0.040	0.040	0.20/0.35	—	—	0.35/0.45	4427
4520	0.18/0.23	0.45/0.65	0.040	0.040	0.20/0.35	—	—	0.45/0.60	4520

ALLOY STEELS (As of July, 1958)

Standard Steels (Continued)

	Chemical Composition Ranges and Limits, per cent								Corresponding SAE Number
AISI Number	C	Mn	P Max.	S Max.	Si	Ni	Cr	Mo	
4615	0.13/0.18	0.45/0.65	0.040	0.040	0.20/0.35	1.65/2.00	—	0.20/0.30	4615
4617	0.15/0.20	0.45/0.65	0.040	0.040	0.20/0.35	1.65/2.00	—	0.20/0.30	4617
4620	0.17/0.22	0.45/0.65	0.040	0.040	0.20/0.35	1.65/2.00	—	0.20/0.30	4620
4621	0.18/0.23	0.70/0.90	0.040	0.040	0.20/0.35	1.65/2.00	—	0.20/0.30	4621
4718	0.16/0.21	0.70/0.90	0.040	0.040	0.20/0.35	0.90/1.20	0.35/0.55	0.30/0.40	4718
4720	0.17/0.22	0.50/0.70	0.040	0.040	0.20/0.35	0.90/1.20	0.35/0.55	0.15/0.25	4720
4815	0.13/0.18	0.40/0.60	0.040	0.040	0.20/0.35	3.25/3.75	—	0.20/0.30	4815
4817	0.15/0.20	0.40/0.60	0.040	0.040	0.20/0.35	3.25/3.75	—	0.20/0.30	4817
4820	0.18/0.23	0.50/0.70	0.040	0.040	0.20/0.35	3.25/3.75	—	0.20/0.30	4820
5015	0.12/0.17	0.30/0.50	0.040	0.040	0.20/0.35	—	0.30/0.50	—	5015
5046	0.43/0.50	0.75/1.00	0.040	0.040	0.20/0.35	—	0.20/0.35	—	5046
5115	0.13/0.18	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5115
5120	0.17/0.22	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5120
5130	0.28/0.33	0.70/0.90	0.040	0.040	0.20/0.35	—	0.80/1.10	—	5130
5132	0.30/0.35	0.60/0.80	0.040	0.040	0.20/0.35	—	0.75/1.00	—	5132
5135	0.33/0.38	0.60/0.80	0.040	0.040	0.20/0.35	—	0.80/1.05	—	5135
5140	0.38/0.43	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5140
5145	0.43/0.48	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5145
5147	0.45/0.52	0.70/0.95	0.040	0.040	0.20/0.35	—	0.85/1.15	—	5147
5150	0.48/0.53	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5150
5155	0.50/0.60	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5155
5160	0.55/0.65	0.75/1.00	0.040	0.040	0.20/0.35	—	0.70/0.90	—	5160
E50100	0.95/1.10	0.25/0.45	0.025	0.025	0.20/0.35	—	0.40/0.60	—	50100
E51100	0.95/1.10	0.25/0.45	0.025	0.025	0.20/0.35	—	0.90/1.15	—	51100
E52100	0.95/1.10	0.25/0.45	0.025	0.025	0.20/0.35	—	1.30/1.60	—	52100
								V	
6118	0.16/0.21	0.50/0.70	0.040	0.040	0.20/0.35	—	0.50/0.70	0.10/0.15	6118
6120	0.17/0.22	0.70/0.90	0.040	0.040	0.20/0.35	—	0.70/0.90	0.10 Min.	6120
6150	0.48/0.53	0.70/0.90	0.040	0.040	0.20/0.35	—	0.80/1.10	0.15 Min.	6150
								Mo	
8115	0.13/0.18	0.70/0.90	0.040	0.040	0.20/0.35	0.20/0.40	0.30/0.50	0.08/0.15	8115
8615	0.13/0.18	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8615
8617	0.15/0.20	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8617
8620	0.18/0.23	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8620
8622	0.20/0.25	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8622
8625	0.23/0.28	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8625
8627	0.25/0.30	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8627
8630	0.28/0.33	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8630

ALLOY STEELS (As of July, 1958)

Standard Steels (Continued)

AISI Number	Chemical Composition Ranges and Limits, per cent								Corresponding SAE Number
	C	Mn	P Max.	S Max.	Si	Ni	Cr	Mo	
8637	0.35/0.40	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8637
8640	0.38/0.43	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8640
8642	0.40/0.45	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8642
8645	0.43/0.48	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8645
8650	0.48/0.53	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8650
8655	0.50/0.60	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8655
8660	0.55/0.65	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	8660
8720	0.18/0.23	0.70/0.90	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.20/0.30	8720
8735	0.33/0.38	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.20/0.30	—
8740	0.38/0.43	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.20/0.30	8740
8742	0.40/0.45	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.20/0.30	8742
8822	0.20/0.25	0.75/1.00	0.040	0.040	0.20/0.35	0.40/0.70	0.40/0.60	0.30/0.40	8822
9255	0.50/0.60	0.70/0.95	0.040	0.040	1.80/2.20	—	—	—	9255
9260	0.55/0.65	0.70/1.00	0.040	0.040	1.80/2.20	—	—	—	9260
9262	0.55/0.65	0.75/1.00	0.040	0.040	1.80/2.20	—	0.25/0.40	—	9262
E9310	0.08/0.13	0.45/0.65	0.025	0.025	0.20/0.35	3.00/3.50	1.00/1.40	0.08/0.15	9310
9840	0.38/0.43	0.70/0.90	0.040	0.040	0.20/0.35	0.85/1.15	0.70/0.90	0.20/0.30	9840
9850	0.48/0.53	0.70/0.90	0.040	0.040	0.20/0.35	0.85/1.15	0.70/0.90	0.20/0.30	9850

NOTE: Grades shown in the above list with prefix letter E generally are manufactured by the basic electric furnace process. All others are normally manufactured by the basic open hearth process but may be manufactured by the basic electric furnace process with adjustments in phosphorus and sulphur.

ALLOY STEELS (As of July, 1958)

TENTATIVE STANDARD STEELS

OPEN HEARTH AND ELECTRIC FURNACE ALLOY STEELS BARS, BILLETS, BLOOMS AND SLABS

The ranges and limits in this table apply to steel not exceeding 200 sq in. in cross-sectional area.

AISI Number	Chemical Composition Ranges and Limits, per cent					
	C	Mn	Si	Ni	Cr	Mo
TS 4140	0.38/0.43	0.80/1.05	0.20/0.35	—	0.90/1.20	0.08/0.15
TS 4150	0.48/0.53	0.80/1.05	0.20/0.35	—	0.90/1.20	0.08/0.15

NOTE: TS denotes tentative standard steels.

ALLOY STEELS (As of July, 1958)

BORON STEELS

(TENTATIVE AND STANDARD)

OPEN HEARTH AND ELECTRIC FURNACE ALLOY STEELS BARS, BILLETS, BLOOMS AND SLABS

The ranges and limits in this table apply to steel not exceeding 200 sq in. in cross-sectional area.

AISI Number Grade	Chemical Composition Ranges and Limits, per cent						
	C	Mn	Si	Ni	Cr	Mo	V
TS 14B35	0.33/0.38	0.75/1.00	0.20/0.35	—	—	—	—
50B40	0.38/0.43	0.75/1.00	0.20/0.35	—	0.40/0.60	—	—
50B44	0.43/0.48	0.75/1.00	0.20/0.35	—	0.40/0.60	—	—
50B46	0.43/0.50	0.75/1.00	0.20/0.35	—	0.20/0.35	—	—
50B50	0.48/0.53	0.75/1.00	0.20/0.35	—	0.40/0.60	—	—
50B60	0.55/0.65	0.75/1.00	0.20/0.35	—	0.40/0.60	—	—
51B60	0.55/0.65	0.75/1.00	0.20/0.35	—	0.70/0.90	—	—
81B45	0.43/0.48	0.75/1.00	0.20/0.35	0.20/0.40	0.35/0.55	0.08/0.15	—
86B45	0.43/0.48	0.75/1.00	0.20/0.35	0.40/0.70	0.40/0.60	0.15/0.25	—
94B15	0.13/0.18	0.75/1.00	0.20/0.35	0.30/0.60	0.30/0.50	0.08/0.15	—
94B17	0.15/0.20	0.75/1.00	0.20/0.35	0.30/0.60	0.30/0.50	0.08/0.15	—
94B30	0.28/0.33	0.75/1.00	0.20/0.35	0.30/0.60	0.30/0.50	0.08/0.15	—
94B40	0.38/0.43	0.75/1.00	0.20/0.35	0.30/0.60	0.30/0.50	0.08/0.15	—

Note: These steels can be expected to have 0.0005 per cent minimum boron content.

TS denotes tentative standard steels.

Standard Boron Steels have identical corresponding SAE numbers.

ALLOY STEELS (As of July, 1958)

STANDARD H-STEELS

OPEN HEARTH AND ELECTRIC FURNACE STEELS BARS, BILLETS, BLOOMS

The ranges and limits in this table apply to material not exceeding 200 sq inches in cross-sectional area.

Steel Designation SAE or AISI	Chemical Composition Ranges and Limits, per cent					
	C	Mn	Si	Ni	Cr	Mo
1330-H	0.27/0.33	1.45/2.05	0.20/0.35	—	—	—
1335-H	0.32/0.38	1.45/2.05	0.20/0.35	—	—	—
1340-H	0.37/0.44	1.45/2.05	0.20/0.35	—	—	—
3140-H	0.37/0.44	0.60/1.00	0.20/0.35	1.00/1.45	0.45/0.85	—
3310-H	0.07/0.13	0.30/0.70	0.20/0.35	3.20/3.80	1.30/1.80	—
4027-H	0.24/0.30	0.60/1.00	0.20/0.35	—	—	0.20/0.30
4028-H*	0.24/0.30	0.60/1.00	0.20/0.35	—	—	0.20/0.30
4037-H	0.34/0.41	0.60/1.00	0.20/0.35	—	—	0.20/0.30
4042-H	0.39/0.46	0.60/1.00	0.20/0.35	—	—	0.20/0.30
4047-H	0.44/0.51	0.60/1.00	0.20/0.35	—	—	0.20/0.30
4063-H	0.59/0.69	0.65/1.10	0.20/0.35	—	—	0.20/0.30
4118-H	0.17/0.23	0.60/1.00	0.20/0.35	—	0.30/0.70	0.08/0.15
4130-H	0.27/0.33	0.30/0.70	0.20/0.35	—	0.75/1.20	0.15/0.25
4135-H	0.32/0.38	0.60/1.00	0.20/0.35	—	0.75/1.20	0.15/0.25
4137-H	0.34/0.41	0.60/1.00	0.20/0.35	—	0.75/1.20	0.15/0.25
4140-H	0.37/0.44	0.65/1.10	0.20/0.35	—	0.75/1.20	0.15/0.25
4142-H	0.39/0.46	0.65/1.10	0.20/0.35	—	0.75/1.20	0.15/0.25
4145-H	0.42/0.49	0.65/1.10	0.20/0.35	—	0.75/1.20	0.15/0.25
4147-H	0.44/0.51	0.65/1.10	0.20/0.35	—	0.75/1.20	0.15/0.25
4150-H	0.47/0.54	0.65/1.10	0.20/0.35	—	0.75/1.20	0.15/0.25
4320-H	0.17/0.23	0.40/0.70	0.20/0.35	1.55/2.00	0.35/0.65	0.20/0.30
4337-H	0.34/0.41	0.55/0.90	0.20/0.35	1.55/2.00	0.65/0.95	0.20/0.30
4340-H	0.37/0.44	0.55/0.90	0.20/0.35	1.55/2.00	0.65/0.95	0.20/0.30
E4340-H	0.37/0.44	0.60/0.95	0.20/0.35	1.55/2.00	0.65/0.95	0.20/0.30
4620-H	0.17/0.23	0.35/0.75	0.20/0.35	1.55/2.00	—	0.20/0.30
4621-H	0.17/0.23	0.60/1.00	0.20/0.35	1.55/2.00	—	0.20/0.30
4720-H	0.17/0.23	0.45/0.75	0.20/0.35	0.85/1.25	0.30/0.60	0.15/0.25

*Sulphur content 0.035/0.050 per cent.

ALLOY STEELS (As of July, 1958)

Standard H-Steels (Continued)

Steel Designation SAE or AISI	Chemical Composition Ranges and Limits, per cent					
	C	Mn	Si	Ni	Cr	Mo
4815-H	0.12/0.18	0.30/0.70	0.20/0.35	3.20/3.80	—	0.20/0.30
4817-H	0.14/0.20	0.30/0.70	0.20/0.35	3.20/3.80	—	0.20/0.30
4820-H	0.17/0.23	0.40/0.80	0.20/0.35	3.20/3.80	—	0.20/0.30
5046-H	0.43/0.50	0.65/1.10	0.20/0.35	—	0.13/0.43	—
5120-H	0.17/0.23	0.60/1.00	0.20/0.35	—	0.60/1.00	—
5130-H	0.27/0.33	0.60/1.00	0.20/0.35	—	0.75/1.20	—
5132-H	0.29/0.35	0.50/0.90	0.20/0.35	—	0.65/1.10	—
5135-H	0.32/0.38	0.50/0.90	0.20/0.35	—	0.70/1.15	—
5140-H	0.37/0.44	0.60/1.00	0.20/0.35	—	0.60/1.00	—
5145-H	0.42/0.49	0.60/1.00	0.20/0.35	—	0.60/1.00	—
5147-H	0.45/0.52	0.60/1.05	0.20/0.35	—	0.80/1.25	—
5150-H	0.47/0.54	0.60/1.00	0.20/0.35	—	0.60/1.00	—
5155-H	0.50/0.60	0.60/1.00	0.20/0.35	—	0.60/1.00	—
5160-H	0.55/0.65	0.65/1.10	0.20/0.35	—	0.60/1.00	—
						V
6120-H	0.17/0.23	0.60/1.00	0.20/0.35	—	0.60/1.00	0.10 min.
6150-H	0.47/0.54	0.60/1.00	0.20/0.35	—	0.75/1.20	0.15 min.
						Mo
8617-H	0.14/0.20	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8620-H	0.17/0.23	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8622-H	0.19/0.25	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8625-H	0.22/0.28	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8627-H	0.24/0.30	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8630-H	0.27/0.33	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8637-H	0.34/0.41	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8640-H	0.37/0.44	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8642-H	0.39/0.46	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8645-H	0.42/0.49	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8650-H	0.47/0.54	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8655-H	0.50/0.60	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8660-H	0.55/0.65	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
8720-H	0.17/0.23	0.60/0.95	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8740-H	0.37/0.44	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8742-H	0.39/0.46	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.20/0.30
8822-H	0.19/0.25	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.30/0.40
9260-H	0.55/0.65	0.65/1.10	1.70/2.20	—	—	—
9262-H	0.55/0.65	0.65/1.10	1.70/2.20	—	0.20/0.50	—
9310-H	0.07/0.13	0.40/0.70	0.20/0.35	2.95/3.55	1.00/1.45	0.08/0.15
9840-H	0.37/0.44	0.60/0.95	0.20/0.35	0.80/1.20	0.65/0.95	0.20/0.30
9850-H	0.47/0.54	0.60/0.95	0.20/0.35	0.80/1.20	0.65/0.95	0.20/0.30

ALLOY STEELS (As of July, 1958)

H-Steels (Continued)

Steel Designation SAE or AISI	Chemical Composition Ranges and Limits, per cent					
	C	Mn	Si	Ni	Cr	Mo
			TENTATIVE STANDARD H-STEELS			
TS 4140-H	0.37/0.44	0.70/1.20	0.20/0.35	—	0.85/1.30	0.08/0.15
TS 4150-H	0.47/0.54	0.70/1.20	0.20/0.35	—	0.85/1.30	0.08/0.15
			TENTATIVE STANDARD BORON H-STEELS*			
TS 14B35-H	0.32/0.38	0.65/1.10	0.20/0.35	—	—	—
			STANDARD BORON H-STEELS*			
50B40-H	0.37/0.44	0.65/1.10	0.20/0.35	—	0.30/0.70	—
50B44-H	0.42/0.49	0.65/1.10	0.20/0.35	—	0.30/0.70	—
50B46-H	0.43/0.50	0.65/1.10	0.20/0.35	—	0.13/0.43	—
50B50-H	0.47/0.54	0.65/1.10	0.20/0.35	—	0.30/0.70	—
50B60-H	0.55/0.65	0.65/1.10	0.20/0.35	—	0.30/0.70	—
51B60-H	0.55/0.65	0.65/1.10	0.20/0.35	—	0.60/1.00	—
81B45-H	0.42/0.49	0.70/1.05	0.20/0.35	0.15/0.45	0.30/0.60	0.08/0.15
86B45-H	0.42/0.49	0.70/1.05	0.20/0.35	0.35/0.75	0.35/0.65	0.15/0.25
94B15-H	0.12/0.18	0.70/1.05	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
94B17-H	0.14/0.20	0.70/1.05	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
94B30-H	0.27/0.33	0.70/1.05	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15
94B40-H	0.37/0.44	0.70/1.05	0.20/0.35	0.25/0.65	0.25/0.55	0.08/0.15

* These steels can be expected to have 0.0005 per cent minimum boron content.

Note 1. The phosphorus and sulphur limitations for each steelmaking process are as follows:

Basic electric furnace — 0.025 per cent maximum
Basic open hearth — 0.040 per cent maximum
Acid electric furnace — 0.050 per cent maximum
Acid open hearth — 0.050 per cent maximum

Note 2. Minimum silicon limit for acid open hearth or acid electric furnace alloy steel is 0.15 per cent.

Note 3. Small quantities of certain elements are present in alloy steels which are not specified or required. These elements are considered as incidental and may be present to the following maximum amounts: Copper, 0.35 per cent; Nickel, 0.25 per cent; Chromium, 0.20 per cent; and Molybdenum, 0.06 per cent.

Note 4. The chemical ranges and limits shown in above Tables are subject to the check analysis tolerances shown in Table on page 44.

Note 5. Where minimum and maximum sulphur content is shown it is indicative of resulphurized steels.

ALLOY STEELS (As of July, 1958)

CHECK ANALYSIS TOLERANCES OVER OR UNDER SPECIFIED RANGE OR LIMIT

OPEN HEARTH AND ELECTRIC FURNACE ALLOY STEELS

Elements	Limit, or Maximum of Specified Element, per cent	Tolerance Over Maximum Limit or Under Minimum Limit for Size Ranges Shown			
		100 sq in. or less	Over 100 to 200 sq in. incl.	Over 200 to 400 sq in. incl.	Over 400 to 800 sq in. incl.
Carbon	To 0.30 incl.	0.01	0.02	0.03	0.04
	Over 0.30 to 0.75 incl.	0.02	0.03	0.04	0.05
	Over 0.75	0.03	0.04	0.05	0.06
Manganese	To 0.90 incl.	0.03	0.04	0.05	0.06
	Over 0.90 to 2.10 incl.	0.04	0.05	0.06	0.07
Phosphorus	Over max. only	0.005	0.010	0.010	0.010
Sulphur	To 0.060 incl.	0.005	0.010	0.010	0.010
Silicon	To 0.35 incl.	0.02	0.02	0.03	0.04
	Over 0.35 to 2.20 incl.	0.05	0.06	0.06	0.07
Nickel	To 1.00 incl.	0.03	0.03	0.03	0.03
	Over 1.00 to 2.00 incl.	0.05	0.05	0.05	0.05
	Over 2.00 to 5.30 incl.	0.07	0.07	0.07	0.07
	Over 5.30 to 10.00 incl.	0.10	0.10	0.10	0.10
Chromium	To 0.90 incl.	0.03	0.04	0.04	0.05
	Over 0.90 to 2.10 incl.	0.05	0.06	0.06	0.07
	Over 2.10 to 3.99 incl.	0.10	0.10	0.12	0.14
Molybdenum	To 0.20 incl.	0.01	0.01	0.02	0.03
	Over 0.20 to 0.40 incl.	0.02	0.03	0.03	0.04
	Over 0.40 to 1.15 incl.	0.03	0.04	0.05	0.06
Vanadium	To 0.10 incl.	0.01	0.01	0.01	0.01
	Over 0.10 to 0.25 incl.	0.02	0.02	0.02	0.02
	Over 0.25 to 0.50 incl.	0.03	0.03	0.03	0.03
	Min. value specified, check under min. limit	0.01	0.01	0.01	0.01
Tungsten	To 1.00 incl.	0.04	0.05	0.05	0.06
	Over 1.00 to 4.00 incl.	0.08	0.09	0.10	0.12
Aluminum	Up to 0.10 incl.	0.03	..	..	..
	Over 0.10 to 0.20 incl.	0.04	..	..	..
	Over 0.20 to 0.30 incl.	0.05	..	..	..
	Over 0.30 to 0.80 incl.	0.07	..	..	..
	Over 0.80 to 1.80 incl.	0.10	..	..	..

BETHLEHEM STEEL COMPANY

GENERAL OFFICES BETHLEHEM STEEL **BETHLEHEM, PA.**

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